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BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 122

Contribution from the Bureau of Soils, Milton Whitney, Chief.
August 24, 1914.

(PROFESSIONAL PAPER.)

THE INORGANIC COMPOSITION OF SOME IMPORTANT AMERICAN SOILS.

By W. O. Robinson, *Scientist in Soil Laboratory Investigations.*

INTRODUCTION.

There is now recorded an enormous number of analyses of extracts of soils. These extracts have been prepared by treating the soil with aqueous solutions of acids, salts, various organic substances, and mixtures. There are, however, very few analyses available of the soil itself—that is, showing the total constituents, or the total amount of any particular constituent—and more especially are wanting such analyses made by quantitative methods of approved validity.

The advancement of soil and biological chemistry requires a knowledge of the actual chemical composition of the soil, including not only the common but the rarer elements. Such data are necessary for the comparison of soils and subsoils, for tracing the genetic relations of soils and rock materials, processes of soil formation, and for studying certain relations of soils and plants. The absorption of mineral nutrients, whether necessary to the plant or merely incidental or accidental, the possible functions of so-called catalytic fertilizers, and many other problems of the soil and plant require a definite knowledge of the mineral composition of the soil. The work presented in the following pages is a systematic investigation of those types of American soils which, for agricultural reasons, are of relatively greater importance. So far as reliable methods have been available, quantitative results are given.

SELECTION OF SOIL TYPES.

The classification of soils which has proved the most practical for field investigations and which is employed in the Bureau of Soils is

Note.—This bulletin gives the results of chemical and mineralogical investigations of certain important soils. The inorganic part alone is considered, and special attention is given to the so-called rarer elements. It is technical and intended for the use of research workers in agricultural chemistry and teachers in the same field. It will also be found of secondary interest to practical agriculturists.

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based primarily on texture and other obvious physical properties. These qualities serve to divide soils into types which are further grouped into series and provinces. The provinces east of the Mississippi are as follows: Piedmont Plateau, Appalachian Mountain and Plateau, Limestone Valley and Uplands, Glacial and Loessial, Atlantic and Gulf Coastal Plains, and River Flood Plains.[1]

In the selection of samples for analysis only important agricultural types were chosen. They were selected to represent various textures, provinces, and conditions of fertility. A comparatively small number of soils were examined. Owing to the time-consuming character of the analysis and the inability to secure samples from places where field parties were not working, the samples do not represent as wide a range as desired.

DISTRIBUTION OF THE RARER ELEMENTS.

It would seem that all elements present in the rocks from which a soil is formed would be present in the soil, for the soil has been shown to contain all the more common rock-forming minerals.[2] While there is great change in chemical composition as a rock weathers to a soil, and much of the more soluble constituents are washed away, it is hardly conceivable that any one element should completely disappear. Had the mineral which contained this one element completely disintegrated, the weathered products might contain the element in an insoluble form, other elements might combine with it to form an insoluble compound, or in case none of these things happened, the soil possesses such a marked capacity for physical absorption that it is doubtful if it would yield the last traces of the soluble element to the soil solution. Further, the soil is by no means stationary, but is continually being translocated by wind and water.[3] It is evident that such processes add to the chemical complexity of the soil.

Provided methods of analysis were sufficiently delicate, we would expect to find in the soil every element for which it is examined, and it would seem, judging from the extreme complexity of the soil, that failure to find an element in the soil shows the method of analysis of insufficient delicacy rather than the absence of the element.

The distribution of the elements in igneous rocks is given by Washington,[4] special attention being paid to the elements in smaller amounts. From this work and from that of Clarke[5] and Hillebrand,[6]

[1] Bul. 96, Bureau of Soils, U. S. Dept. Agriculture (1913), upon which descriptions of the types are based.
[2] See F. K. Cameron and J. M. Bell, Bul. 30, Bureau of Soils, U. S. Dept. Agriculture (1905).
[3] For a full discussion see E. E. Free, Bul. No. 68, Bureau of Soils, U. S. Dept. Agriculture.
[4] Trans. Am. Inst. Min. Eng., 39, 735 (1908).
[5] Data of Geochemistry, Bul. 491, U. S. Geol. Survey (1911).
[6] Analysis of Silicate and Carbonate Rocks, Bul. 422, U. S. Geol. Survey (1910).

the following memoranda are taken concerning the distribution of the rarer elements in igneous rocks. Only those elements reported in the present work are considered.

BARIUM.

This element is found in feldspathic rocks and appears to be associated in some quantitative way with potassium. The occurrence of barium in soils has been very thoroughly treated by Failyer.[1] It was found wherever sought in all soils of the Great Plains, in amounts from 0.02 to 0.11 per cent expressed as the oxide. It was further qualitatively shown to be present in many soils east of the Mississippi. Of all the soils examined only two, the Orangeburg fine sandy loam and Houston clay, from Texas and Alabama, respectively, failed to give the barium reaction in the samples tested.

CÆSIUM.

This is the rarest of the alkalies. It has been found in spring water and reported in the ash of the sugar beet by Von Lipman,[2] and Vernadski[3] has found spectroscopic traces in feldspars and micas, so that in very small quantities at least it may be expected in rocks and soils.

CHROMIUM.

This element occurs more especially in the ferromagnesian rocks, though in small amounts. It has been reported in soils and the ash of plants.

COPPER.

Copper appears to be widely distributed and to be more abundant in the basic rocks. However, Hillebrand points out that there is great danger of contamination during the process of analysis by copper from numerous copper utensils employed. It has been reported in a number of plants to which it must have come from the soil.

LITHIUM.

Washington states that lithium often occurs in rocks high in sodium. It is widely distributed but seldom occurs in more than spectroscopic traces, except in its characteristic minerals.

MANGANESE.

Manganese is hardly to be considered as a rare element, though it is present in rocks and soils in small amounts. It is widely distributed. The analytical results for manganese in soils hitherto reported are probably inaccurate.

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[1] Bul. 72, Bureau of Soils, U. S. Dept. Agriculture (1910).
[2] Ber., 21, 3492 (1889).
[3] Bul. Acad. St. Petersburg, 821 (1909).

MOLYBDENUM.

Hillebrand has found molybdenum to be present in the very siliceous rocks, though in amounts too small to determine quantitatively. Demarcay [1] has detected it in the ash of the grapevine and various trees, so that its occurrence in soils is possibly quite common even if in very minute quantities.

NICKEL.

Nickel occurs associated with cobalt in certain ferromagnesian rocks and in some sulphides. The amount present is very small. Like copper, there may be contamination with nickel during the process of analysis. Tending to an error in the opposite direction, however, is the known solubility of certain of its precipitates in the reagents employed.

RUBIDIUM.

This alkali has been reported in springs and brines. Vernadski [2] found it in spectroscopic traces in various feldspars and micas, and Pfeiffer [3] has reported it present in sugar beets and tobacco.

THE RARE EARTHS.

This group of elements appears to be associated with rocks high in silica and possibly sodium.

VANADIUM.

Demarcay [1] and Von Lipman [4] report vanadium in the ash of the grapevine, sugar beet, and various trees. It is widely distributed, more especially in the basic rocks, though in small amounts.

ZIRCONIUM.

Zirconium occurs in largest amounts in rocks high in silica and sodium. It rarely amounts to 0.2 per cent and is usually less than 0.05 per cent. Zirconium is present in soils as the silicate. A careful microscopic examination of any soil generally shows the presence of zircons.

PREPARATION OF THE SAMPLE.

The samples were collected from one or two spots considered typical by men familiar with the soil type. One hundred pounds of the surface soil, after taking off the sod, were collected, and then the subsoil taken directly underneath to a depth of 3 feet when rock strata did not make it impossible. Care was taken to keep the sides of the hole perpendicular. Only iron tools were used in the sampling and the samples were shipped in clean grain sacks.

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[1] Compt. Rend., **130**, 91 (1900).
[2] Bul. Acad. St. Petersburg, 1909, 821.
[3] Arch. Pharm. [2] **150**, 97–102.
[4] Loc. cit.

When received at the laboratories the sample was spread on brown wrapping paper and allowed to air-dry. It was then passed through an iron sieve of 6 meshes to the linear inch. The soil clods not passing were crushed with a wooden rolling-pin on brown paper and passed through the sieve. The stones, sticks, roots, etc., were rejected.

The soil passing through the sieve was well mixed and quartered down to a subsample of 7 to 10 pounds. This was crushed in an iron mortar to break up the larger soil particles, such as iron and manganese concretions and the like. It was then quartered down to a sample of 50 grams, which was ground till it passed entirely through a silk bolting cloth of 100 meshes to the linear inch.

In this work of subsampling and grinding great care was taken, for it was recognized that in some cases the rarer elements were segregated in comparatively large pieces of their mineral species. For instance, manganese is often found in large concretions and zircons occur in fairly large, hard crystals. If such samples were not carefully ground and mixed, that portion taken for analysis might contain an undue number of these crystals or concretions.

NOTES ON THE METHODS OF ANALYSIS.

For the determination of the major constituents the soil was first ignited to destroy organic matter, then fused with sodium carbonate, following the procedure outlined by Hillebrand.[1] Where there were choices of different methods or special difficulties encountered, variations were adopted. Notes explaining these points are given below.

IRON AND ALUMINUM.

Generally soils are higher in iron and aluminum than rocks and contain but little manganese and comparatively small quantities of calcium and magnesium. The precipitate of the iron and aluminum group, obtained by the use of sodium acetate, is difficult to handle when large, and has a tendency to run through the filter. Although this part was filtered off when the filtrate from the iron group was concentrated, the precipitate of the calcium oxalate contained much more iron and aluminum than when the iron group was precipitated with ammonia. Accordingly precipitation of this group was made with ammonia. Manganese may have been present in the iron group precipitate, but in small quantity only, for nearly all was recovered in the ammonium sulphide precipitate, as shown by a comparison of the amount obtained in this way with the total amount determined by the use of hydrofluoric acid on another sample of the soil.

[1] Bul. 422, U. S. Geol. Survey (1910).

MANGANESE.

Contrary to the experience of Gortner and Rost [1] the method for the determination of manganese outlined by Hillebrand [2] has given excellent results. If the soil was finely ground and ignited prior to the treatment with hydrofluoric and sulphuric acids, the insoluble residue [3] contained only the merest traces of manganese, and in many cases gave no color whatever. The residue was fused with sodium carbonate with a very little niter, and in case the color indicated manganese the melt was dissolved in acid and oxidized to permanganate. In all cases the manganese in the residue was below 0.01 milligram of manganous oxide, MnO.

FERROUS IRON.

Ferrous iron is undoubtedly present in soils, for ferrous minerals are common constituents, as shown by microscopic examination.[4] But since organic matter is invariably present, no attempt was made to estimate ferrous iron, for there is a certainty that some ferric iron would be reduced during the analytical operations, and, further, if titration with permanganate solution were attempted some permanganate might be reduced by persisting organic matter. The iron is therefore calculated as ferric oxide.

LOSS ON IGNITION.

The loss on ignition is a figure difficult to duplicate, especially in soils high in iron and aluminum. Although the crucibles were subjected to a comparatively low temperature and an oxidizing flame, there was probably some reduction by the organic matter. Since the sum of the constituents is in most cases well over 100, it is probable that errors due to this cause were greater than those due to the imperfect dehydration of hydrated minerals.

SULPHUR.

The ignitions with sodium carbonate and nitrate for the determination of sulphur were made in an electric furnace, thus avoiding any contamination by the sulphur of a gas flame.

RARE EARTHS.

The results obtained for the rare earths are to be taken as qualitative in nature, that is, as showing the presence of the rare earths rather than the absolute amounts. However, work by different analysts

[1] J. Ind. Eng. Chem., **4**, 522 (1912).

[2] Bul. 422, U. S. Geol. Survey, p. 116.

[3] This residue contained zircons, fluorides of calcium and the rare earths, barium sulphate, and, strange as it may seem, fragments of quartz.

[4] McCaughey and Fry, Bul. 91, Bureau of Soils, U. S. Dept. Agr. (1913).

agreed fairly well and concordant results were obtained by both the preferred and alternative method outlined by Hillebrand.

NICKEL AND COBALT.

These elements were found in determinable amounts in the first soils analyzed. Later in the work only traces were found. The crucibles in which the fusions were made had been previously used in fusions of material which had been precipitated from an ammoniacal liquid coming into contact with nickel plate. It is not impossible that some of the nickel reported in the first eight anaylses might have come from that previously absorbed by the crucible, although they were scrupulously cleaned by fusion with potassium bisulphate and sodium carbonate prior to the first soil fusion. A blank fusion after the first six analyses showed no nickel. Noyes, Bray, and Spear [1] have shown that nickel sulphide is not completely insoluble in cold hydrochloric acid (1:1 HCl), and since the method used calls for this separation, further work with this process was discontinued.

COPPER.

Copper was detected in the precipitate for nickel, cobalt, and copper. Since there is a possibility that there might have been contamination from the copper steam baths, by means of air currents carrying the oxidized copper, the presence of the element at this point in the analytical operations is not to be taken as indicating that it is present in the soil.

MOLYBDENUM.

The test used for molybdenum was that recommended by Hillebrand. It is very delicate.

LITHIUM, CÆSIUM, AND RUBIDIUM.

Lithium was invariably present, giving stronger tests in some instances than in others. For the identification of this element and also for cæsium and rubidium, a Hilger wave-length spectroscope was used. For lithium the line 6708.2 was used. The two doublets 4593.3–4555.4 and 4215.6–4201.9 served to identify cæsium and rubidium respectively. To determine the rare alkalies 10 grams of soil were fused with 10 grams of calcium chloride and 40 grams of calcium oxide for 4 hours. The chlorides of all the alkalies were obtained by the method of J. Lawrence Smith. To the solution of the chlorides about 0.05 gram of platinic chloride was added, the solution stirred, and evaporated to pastiness. The unchanged chlorides were rapidly dissolved in a minimum amount of hot water, the platinum salts washed onto a small carbon filter, dried and re-

[1] A System of Qualitative Analysis, p. 78.

duced with hydrogen. The chlorides of the rare alkalies, together with a comparatively large amount of potassium chloride, were washed through with hot water into a very small dish, evaporated to dryness, taken up, and filtered off with 3 portions of 4 drops each of strong hydrochloric acid. By this method 0.0001 gram of rubidium or cæsium mixed with 10 grams of soil could easily be separated and identified. The method of Gooch and Phinney [1] for the identification with the spectroscope was followed. On account of the large amount of potassium present, quantitative refinement was not attempted, though the results obtained are given in four magnitudes. These magnitudes were obtained by comparison with four known amounts of rubidium treated in exactly the same manner as the soils tested.

PHOSPHORIC ACID.

Considerable difficulty was experienced in getting concordant results with this determination. The phosphoric acid solution was obtained in two ways—by fusion with sodium carbonate and solution in nitric acid and by decomposition with hydrofluoric and nitric acids. Both methods yield results which agree well. The main difficulty seems to be in preventing the separation of a flocculent precipitate, either from the solution or from the glass which may be attacked by the ammoniacal solution. This flocculent precipitate increases on standing. Woy's [2] method of weighing the gently ignited molybdate precipitate gives results slightly lower than the magnesia method, though it may be as near the truth when the amount of vanadium in the soil is small.

OTHER ELEMENTS.

The results for barium, manganese, strontium, zirconium, and chromium were sharp and clear cut and are believed to be reliable. The vanadium determinations, however, were somewhat uncertain as to absolute amount, though confirmatory tests with hydrogen peroxide and nitric acid showed the element to be present in all cases and showed a depth of color proportional to the amount found by titration.

Throughout the work double precipitations were performed, except in special instances, and blanks were made in all cases. The corrections for calcium and magnesium in the reagents and that derived from the solubility of the glass were quite large, considering the amounts present in the soil. Evaporation, precipitations at the boiling point, etc., were made in platinum, but filtrates were caught in glass, and funnels and stirring rods made of glass were used.

The silica not precipitated in the first and second evaporation was separated from the iron group and suitable corrections made. Calcium was invariably present in the magnesium precipitate and re-

[1] Am. J. Sci., **44**, 392 (1892). [2] Tredwell, **2**, 348, New York (1906).

markably uniform in amount. This represents the solubility of calcium oxalate in aqueous ammoniacal solutions of sodium and ammonium chlorides, together with that dissolving during washing. It appears to be independent of the amounts of calcium and magnesium present. In this work the amount of calcium oxide separated from the precipitated magnesium was almost uniformly 0.7 milligram for the first 18 soils. This correction was applied in the last 8 analyses, instead of making the separations.

The amount of manganese in the magnesium precipitate was so small that no correction was made for this impurity.

All calculations except water (H_2O) at 110° are based on the weight of the soil dried at 110° C.

DESCRIPTION OF THE SAMPLES.

(1) Norfolk sandy loam, 3 miles southwest of Laurinburg, N. C. Depth 0 to 14 inches. This type is formed from the outwash of the more resistant soil particles of the higher formations farther inland. It is a light yellowish sandy loam of the Coastal Plain province, and generally considered productive. This particular sample was taken from virgin soil covered with longleaf pine, white oak, hickory, and occasional dogwood trees. No stones larger than $\frac{1}{8}$ inch were found.

(2) Norfolk sandy loam, subsoil of No. 1, depth 14 to 36 inches. No stones larger than $\frac{1}{8}$ inch in diameter were found.

(3) Decatur clay loam, 1 mile east of Hollywood, Ala. Depth 0 to 4 inches. This soil is derived from the decomposition of limestone and Knox dolomite. It belongs to the Limestone Valley and Uplands province. It is of a dull-red color and considered fertile. The sample was taken from an uncultivated spot forested with shortleaf pine, hickory, white and red oak, persimmon, and shrubs of different species and native grasses. No stones larger than $\frac{1}{8}$ inch were found.

(4) Decatur clay loam, subsoil of No. 3, depth 4 to 15 inches. No stones larger than $\frac{1}{8}$ inch in diameter were found.

(5) Hagerstown loam, 1 mile northwest of Conshohocken, Pa. Depth 0 to 8 inches. This type is derived from the weathering of limestone and belongs to the Limestone Valley and Upland province. The sands are rich in mineral species. It is one of the best general farming types in the eastern States. The sample was taken from a potato field. The texture was that of a mellow brown silty loam. This sample contained 1.8 per cent stones. Of this amount 92.4 per cent was quartz, 5.6 per cent limonite, and 1.8 per cent mica schist.

(6) Hagerstown loam, subsoil of No. 5, depth 8 to 24 inches. This sample contained 5.1 per cent of stones. Of this 90.0 per cent was quartz and 9.1 per cent mica schist.

(7) Volusia silt loam, 3½ miles southwest of Naples, N. Y. Depth 0 to 8 inches. This soil is of the Glacial and Loessial province and is formed from sandstone and shale, with a small portion of material from other sources, mixed in by glacial action. This sample was taken from a "slashing," from which the virgin forest of pine, chestnut, and oak had been removed 40 years ago. In color and texture it is a yellow silt loam. A cultivated field of the same soil type near by has produced very poor crops, and this sample would therefore be considered relatively infertile. The soil contains 7.5 per cent stones. This coarse rock material was 82 per cent shale, 9.5 per cent crystalline, 5 per cent sandstone, and 3 per cent flint.

(8) Volusia silt loam, subsoil of No. 7, depth 8 to 36 inches. This sample contained 32 per cent of stone. Of these 87.5 per cent was shales, 10 per cent sandstones, 2 per cent flint, and 0.5 per cent crystalline.

(9) Marshall silt loam, T. 34 N., R. 54 W., 1 mile north of Edgerton, Mo. Depth 0 to 15 inches. This type is of the Glacial and Loessial province, and is derived from loessial deposits. It is nearly black in color. The Marshall silt loam is the most important corn soil in the United States and supports other crops well. In productiveness it would be graded generally as good to excellent. This sample contained no stones.

(10) Marshall silt loam, subsoil of No. 9, depth 15 to 36 inches. This sample contained no stones.

(11) Gloucester stony loam, 3 miles east of Marlboro, N. H. Depth 0 to 8 inches. This soil is of the Glacial and Loessial province and is derived from materials mainly from granite, mica schist, and other crystalline rocks, ground up and mixed by glacial action. It is grayish yellow in color and full of small stones. The sample was taken in a field that had been in grass for eight years. No fertilizer had been added during that time. The crop was light, though adjoining fields, which were well cultivated, produced good crops. As a type its fertility is considered low to fair. This sample was fairly productive. This soil contained 6.5 per cent of stone. Of this amount 16 per cent was amphibolite, 40 per cent mica schist, 31 per cent granite, and 13 per cent quartz.

(12) Gloucester stony loam, subsoil of No. 11, depth 8 to 36 inches. This sample contained 3 per cent of stone. Of this amount 56 per cent was mica schist, 32 per cent granite, and 12 per cent quartz.

(13) Carrington loam, Sec. 24, T. 11 N., R. 10 E., Lowville Township, Columbia County, Wis. Depth 0 to 11 inches. This is a brownish black mellow loam formed from glacial till. It belongs to the Glacial and Loessial province. As a type it is of excellent fer-

tility. The sample was taken from a potato field. The kind and amount of fertilization given is not known. This sample contained 2.2 per cent of stone. Of this amount 77 per cent was decomposed granite, 15 per cent quartz, and 8 per cent diabase.

(14) Fox fine sand, T. 11 N., R. 11 E., Otsego Township, Columbia County, Wis. Through an error the subsoil of this type was analyzed rather than that of the Carrington loam. Fox fine sand is of the Glacial Lake and River Terrace province and is derived from glacial outwash or valley fill. The sample was taken from an old outwash field. It is of low fertility and subject to eolian erosion and deposition. This sample contained no stones.

(15) Cecil clay, 2½ miles northwest of Charlotte, N. C. Depth 0 to 6 inches. It is of Piedmont Plateau province and is derived from granite, gneiss, and other crystalline rocks. The Cecil clay is a reddish clay loam to clay underlain by a stiff tenacious red clay. Both soil and subsoil contain considerable sand which is characterized by a large proportion of minerals other than quartz. It is one of the strongest soils of the Piedmont Plateau and is used for general farming. This soil would be considered productive. It contained no stones.

(16) Cecil clay, subsoil of No. 15, depth 6 to 36 inches. This sample contained no stones.

(17) Cecil sandy loam, 3½ miles southwest of Charlotte, N. C. Depth 0 to 8 inches. This soil is derived from granite, gneiss, and to a less extent from other crystalline rocks. It is a gray to yellowish sandy loam, underlain by a red brittle clay. It belongs to the Piedmont Plateau province and can be successfully used for cotton, corn, and forage crops. This particular sample was poor and had not been fertilized in recent years. This soil differs from its subsoil more than any other in the series in texture, color, and chemical composition. There were no stones in this sample.

(18) Cecil sandy loam, subsoil of No. 17, depth 8 to 36 inches. This sample contained no stones.

(19) Durham sandy loam, 1¾ miles northeast of Archer, Johnson County, N. C. Depth 0 to 10 inches. This sandy loam is formed mainly from light-colored, medium-grained granite. It is a light-yellow sandy loam of the Piedmont Plateau, lying along the border of the Coastal Plain province. The field from which this sample was taken had been cultivated for some years and produced poor yields. Little, if any, fertilizer had been applied in recent years. The sand of this soil contained a large percentage of potash feldspar, derived from a light-colored granite. There were no stones in this soil.

(20) Durham sandy loam, subsoil of No. 19, depth 10 to 36 inches. This sample contained no stones.

TABLE I.—*Showing the chemical composition of important*

[Analyses by W. O. Robinson.]

Constituents.	Coastal Plains province.		Limestone Valley and Uplands province.				Glacial and Loessial province.					
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
SiO_2	94.50	85.30	79.35	74.81	70.99	66.49	75.12	74.64	73.61	71.43	65.68	73.80
TiO_2	.71	.91	1.15	1.28	1.01	1.01	.68	.70	.71	.77	.79	.71
Al_2O_3	2.07	8.82	8.89	12.80	11.39	14.80	10.49	12.26	9.67	13.44	14.15	13.24
Fe_2O_3	.83	1.91	4.44	5.28	4.23	5.99	4.13	5.01	3.54	4.28	5.67	4.37
MnO	.007	.004	.070	.053	.180	.100	.022	.036	.120	.104	.068	.072
Cr_2O_3	.004	.007	.018	.008	.004	.005	.009	.010	.006	.013	Trace.	.009
V_2O_5	.01	.01	.02	.02	.08	.06	.02	.05	.06	.04	.08	.05
Rare earths	.02	.03	.01	.02	.08	.03	.02	.02	N. T.	N. T.	N. T.	N. T.
ZrO_2	.02	.05	.01	.05	.08	.07	.03	.05	.06	.04	.04	.02
MoO_2	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.
NiO+CoO	Doubt.	Doubt.	N. T.	N. T.	N. T.	N. T.	.04	.06	N. T.	N. T.	N. T.	N. T.
CuO	N. T.	N. T.	N. T.	N. T.	N. T.	N. T.	P.	P.	N. T.	N. T.	N. T.	N. T.
CaO	.39	.38	.63	.40	.93	.35	.49	.37	1.08	1.40	1.36	1.19
BaO	.094	.004	.021	.027	.060	.063	.042	.041	.084	.084	.53	.051
SrO	.02	.03	.04	.04	.11	.11	.04	.05	.03	.01	.05	.03
MgO	.09	.19	.39	.33	1.08	1.93	.48	.90	.77	1.28	.83	.39
K_2O	.10	.12	.67	.75	2.71	3.58	1.40	1.99	2.28	2.03	2.16	2.22
Na_2O	.11	.07	.24	.16	.82	.66	.90	.99	1.03	.63	1.39	1.75
Li	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.
Rb	.001	.001	.001	.001	.002	.002	.002	.002	.002	.002	.002	.002
Cs	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.
P_2O_5	.06	.04	.18	.15	.19	.16	.18	.15	.22	.16	.15	.11
SO_3	.07	.13	.13	.19	.39	.14	.09	.10	.17	.14	.17	.03
Ignition loss	1.74	3.22	4.80	4.63	6.08	5.06	4.44	3.59	7.44	5.56	9.52	3.13
Water at 110°	.48	1.48	1.99	2.38	1.61	1.40	2.03	1.28	2.94	4.12	3.39	1.18
Organic matter (1)	1.13	.29	1.96	.93	2.87	.82	2.43	.60	4.29	2.72	7.07	1.39
CO_2 from carbonates	N. F.	N. F.	N. F.	N. F.	.33	.56	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.

N. T. Not tested. N. F. Not found. P. Present. (1) Determinations by W. B. Page, of this bureau.

(21) York silt loam, Bethany, S. C., ¾ mile east of Kings Mountain battleground. Depth 0 to 10 inches. This soil is derived from imperfectly crystalline rocks, consisting mostly of talcose and micaceous schists. It belongs to the Piedmont Plateau province. In appearance it is an almost white silty loam full of small spangles of mica. The spot from which this sample was taken supports a virgin growth of shortleaf pine and red oak. Nearby fields were in poor condition and the type is markedly infertile. This sample contained 7.6 per cent stones. Of this amount 59 per cent was quartz and 41 per cent was mica schist.

(22) York silt loam, subsoil of No. 21, depth 10 to 22 inches. This sample contained 8 per cent of stones. Sixty per cent was quartz and 40 per cent mica schist. The mica schist particles had largely disintegrated and fell to pieces when washed with water.

(23) Louisa loam, 1¼ miles southeast of Trevilians, Va. Depth 0 to 12 inches. This type belongs to the Piedmont, and is formed from talcose and micaceous schists and imperfectly crystalline slates. It is a friable pale-yellow loam. The sample was taken from a woodland, principally of Spanish and red oak. Nearby fields supported scant crops, and the fertility would be considered low. This sample

types of American soils—Fusion analysis for total constituents.

[Analyses by W. O. Robinson.]

Glacial and Loessial province—Con.		Piedmont Plateau province.											
No. 13.	No. 14.	No. 15.	No. 16.	No. 17.	No. 18.	No. 19.	No. 20.	No. 21.	No. 22.	No. 23.	No. 24.	No. 25.	No. 26.
Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
73.50	76.86	66.49	44.15	88.57	55.69	80.79	69.35	76.71	74.38	84.58	74.99	74.33	71.76
.59	.60	1.02	1.14	.55	.91	.55	.60	.41	.40	1.51	1.59	1.04	1.06
9.10	9.49	17.11	27.58	5.76	24.42	10.55	18.04	12.85	16.31	5.54	10.90	11.00	14.36
4.30	3.79	7.43	16.23	1.55	8.83	1.61	3.42	2.81	2.56	3.30	6.75	4.64	5.82
.113	.062	.51	.033	.044	.022	.017	.014	.005	.005	.045	.039	.136	.109
.010	.010	.013	.025	.002	.006	.004	.002	.007	.004	.013	.014	.006	.007
.03	.03	.05	.06	.01	.04	.02	.02	.04	.03	.03	.03	.03	.05
N. T.	N. T.	.02	.02	.03	.04	.03	.01	.02	.02	.04	N. T.	N. T.	N. T.
.05	.04	.003	.01	.04	.01	.08	.06	.04	.01	.08	.02	.05	.04
N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	P.	N. F.	P.	N. F.	N. F.	N. F.	N. F.	N. F.
N. T.	N. T.	.04	.04	.03	Doubt.	.04	.03	N. T.	N. T.	N. T.	N. T.	N. T.	N. T.
N. T.	N. T.	P.	P.	P.	P.	P.	P.	N. T.	N. T.	N. T.	N. T.	N. T.	N. T.
.94	.93	.36	.44	.39	.40	.89	.72	.08	.21	.21	.26	1.13	1.73
.063	.048	.063	.027	.039	.042	.112	.098	.287	.360	.037	.030	.053	.053
.05	.05	.04	.03	.01	.01	.05	.04	.05	.03	.04	.03	.04	.03
.71	.58	.31	.09	.21	.29	.19	.29	.29	.38	.25	.32	.69	1.06
2.03	1.04	.62	.61	.82	1.06	3.96	3.34	3.26	4.07	.74	.97	1.57	1.50
1.67	1.22	.16	.15	.16	.14	.87	.89	.39	.30	.14	.28	1.53	1.54
P.	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.	P.
.001	.001	Trace.	Trace.	.001	.001	.01	.01	.001	.001	.001	.001	.002	.002
N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.
.24	.20	.17	.15	.08	.07	.12	.12	.05	.05	.12	.15	.16	.10
.13	.18	.07	.07	.04	.09	.06	.06	.12	.14	.15	.16	.15	.10
7.70	4.76	8.06	11.83	2.93	8.94	1.41	4.54	3.16	2.80	3.89	4.72	4.51	2.83
2.75	2.03	2.47	2.90	.53	2.00	.48	1.53	.47	.22	.92	1.43	1.72	2.06
4.94	2.62	1.26	.27	1.46	.09	.40	.33	1.78	.41	2.40	1.04	1.99	1.21
N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.	N. F.

contained 11.2 per cent stones; of this amount 53 per cent was ferruginous quartz, 43 per cent quartz, 3 per cent clay nodules, and 1 per cent mica schist.

(24) Louisa loam, subsoil of No. 23, depth 12 to 30 inches. This sample contained 20 per cent of stones. Seventy-seven per cent was quartz, 15 per cent ferruginous quartz, and 8 per cent clay nodules.

(25) Penn silt loam, ½ mile west of Penn Square, Morristown, Pa. Depth 0 to 9 inches. This soil belongs to the Piedmont Plateau province and is derived from sandstones of Triassic age. It is a light Indian-red mellow silt loam with a darker silty clay subsoil. The sample was taken from a field supporting a good stand of grass, having been cleared 13 years ago and since then used for corn, wheat, and grass in regular rotation. No commercial fertilizer has been added, but an application of about 5 tons of barnyard manure to the acre was made every three years. In general this soil is used for general farm crops and is considered a productive type. No stones were present in this sample.

(26) Penn silt loam, subsoil of No. 25, depth 9 to 24 inches. This sample contained no stones.

DISCUSSION OF THE RESULTS.

The most important generalization to be drawn from Table I is that most of the rarer elements tested for were found in all the soils. They seem to be rather evenly distributed among the various soil types and provinces. The barium of the York silt loam soil and subsoil is remarkably high. There appears to be some quantitative relation between barium and potassium. Strontium does not appear to be associated with barium, nor do these elements appear to be combined with sulphur. Molybdenum was proved to be present in two cases only.

Rubidium was detected in all soils examined. In addition to the soils given in Table I it has been found in Colorado sand from Colorado, Knox silt loam from Missouri, Oswego silt loam from Kansas, and Greenville sandy loam from Georgia. Cæsium was proved to be present in only one soil, Colorado sand, from Greeley, Colo. Since Vernadski [1] has found cæsium to be widely distributed in feldspars and micas it would seem that there must be small amounts present in all soils, since all soils contain large quantities of either feldspars or micas.

The amounts of the rare earths precipitates were too small to separate into simpler groups or elements. The precipitate probably contained cerium for the most part, with a smaller amount of thorium. Thorium has been reported in an Italian soil to the amount of 1 part of thorium oxide to 60,000 parts of soil by Blanc,[2] and Joly [3] has found it in sedimentary rocks in amounts averaging about 1.2×10^{-5} grams per gram of rock, or 1 part in 70,000.

Nickel and cobalt are probably generally present in soils; the figures given do not have quantitative significance, however, and are subject to the doubts referred to in the paragraph on methods. Further work is needed to establish the amounts of these elements present in soils and also to prove definitely the presence of copper in anything but the merest traces.

Since the number of soils in the Coastal Plain and Limestone Valley and Upland provinces analyzed was small, the partial analyses of such soils reported by Failyer, Smith, and Wade [4] are given in Table II for the purpose of comparison.

Soils of the Glacial and Loessial province are higher in calcium, magnesium, sodium, and organic matter than those of the Piedmont Plateau or Coastal Plains. Whereas most of the soils of the Piedmont Plateau are low in potash, the large amount in numbers 19, 20, 21, and 22 brings the average up to that of the glaciated areas.

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[1] Bul. Acad. St. Petersburg (1909), 821.
[2] Atti. Accad. Lincei., **17**, I, 101.
[3] Phil. Mag., **20**, 353.
[4] Bul. 54, Bureau of Soils, U. S. Dept. Agriculture (1908).

TABLE II.—*Partial composition of soils analyzed by Failyer, Smith, and Wade.*

COASTAL PLAIN SERIES.

Soil type and location.	CaO.	MgO.	K_2O.	P_2O_5.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Collington sandy loam, New Jersey	0.12	0.13	0.79	0.03
Norfolk sand, Maryland	.13	.19	.60	.06
Norfolk loam, Maryland	.24	.10	.79	.07
Leonardtown loam, Maryland	.07	.29	1.11	.03
Orangeburg sandy loam, Alabama	.08	.05	.28	.06
Crowley silt loam, Louisiana	.19	.29	.92	.14
Orangeburg fine sandy loam, Texas	.14	.10	.42	.11
SOILS DERIVED FROM LIMESTONES AND SHALES.				
Oswego silt loam, Kansas	0.40	0.36	1.24	0.12
Hagerstown loam, Tennessee	.40	.56	.77	.12
Hagerstown clay, Kentucky	3.12	1.54	4.30	.40
Houston clay, Alabama	28.02	1.21	1.01	.59

Soils formed from limestone may be low in lime, as is shown by the Oswego silt loam and the Hagerstown loam in Table II and by Nos. 3 and 4 in Table I.

During the process of formation and changes in the soil, manganese, with one exception, appears to be concentrated in the surface layers. This seems to be due to a difference in the solubility of the salts of lower and higher states of oxidation. Solutions of reduced manganese could move unchanged in the subsoil, but on coming near the surface, where oxidizing conditions prevail, the manganese would be precipitated as the nearly insoluble higher oxide. Plants might accumulate certain elements selectively absorbed as food in the surface soil, provided such elements were not soluble in atmospheric conditions. Phosphorus has undergone a similar concentration, and it would seem that in this case the larger part of the concentration was effected by the selective absorption of this element by plants, the plants yielding their phosphoric acid to the soil by decomposition and this element being held in the surface soil in difficultly soluble combinations with the ever present bases.

The most striking differences in composition between the surface soil and the subsoil is shown by the silica content. This difference is greater in soils profoundly weathered and subject to erosion and less in the glaciated soils. Complementary to this silica variation is the variation in iron, aluminum, and, generally, titanium. It seems that at the surface erosion has carried away the finer particles containing large amounts of iron and aluminum and has left the larger sand grains, consisting mostly of quartz, in the surface soil. Some of the finer particles might have been driven into the subsoil by rain, or by the movements incident to alternate wetting and drying, but it would seem that by far the larger part of the concentration was effected by surface wash.

Gloucester stony loam, Nos. 11 and 12, shows a greater amount of silica in the subsoil and the iron and aluminum does not follow the general rule of being greater in amount in the subsoil. It would seem that the samples used in analysis might have been transposed, but the analysis of a second sample showed the same relation. This type is an exception to the rule, though the difference in the composition of the surface soil and the subsoil is not great.

Potash and magnesia are noticeably higher in the subsoil. In the Durham sandy loam, Nos. 19 and 20, the sands, or larger soil particles, are mostly potash feldspars. This fact accounts for the greater amount of potash in the surface soil. Barium and lime do not seem to have been concentrated in either layer of the soil. Zirconium appears in the surface soil in larger amounts. The particles of mineral containing this element are comparatively coarse and resist surface wash.

The average amount of sulphur trioxide present in these soils is 0.13 per cent, whereas phosphorus pentoxide averages 0.14 per cent. In one case there is one-fourth as much sulphur trioxide as phosphorus pentoxide. These facts support the evidence brought out by Hart and Peterson [1] and further by Shedd [2] that the sulphur content of soils is lower than that of phosphorus. The average of 16 Wisconsin soils was 0.08 per cent SO_3 and 131 Kentucky soils averaged 0.06 per cent SO_3. Hart and Peterson point out that average crops of cereals remove in the grain and straw two-thirds as much sulphur as phosphorus, grasses about the same, alfalfa somewhat more, and cabbage and turnips 2 to 3 times as much. They advise that sulphur be considered in fertilizer practices.

MINERALOGICAL COMPOSITION.

The micro-petrographical determinations were made by W. J. McCaughey, now of the University of Ohio, and William H. Fry, of this bureau. The examinations were made on separates made by mechanical analysis.

Quartz was universally present in all the soils examined and its presence is not noted in the individual reports.

(1) NORFOLK SANDY LOAM, SOIL.

No. 4 sand.—Practically pure quartz sand with apatite and rutile inclusions.

No. 5 sand.—Nearly pure quartz sand, with a few subangular, though mostly clear, well-rounded grains. Minerals other than quartz, 3.5 per cent. Rutile, zircon, ilmenite, and tourmaline present.

[1] Wis. Agr. Expt. Sta., Research Bul. No. 14. [2] Ky. Agr. Expt. Sta. Bul. No. 174.

Silt.—Minerals other than quartz, 40 per cent; potash feldspars, 7 per cent; muscovite, 0.5 per cent. Epidote is present in fairly large quantities. Hornblende, rutile, zircon, chlorite, magnetite, and sponge spicules are also present.

(2) NORFOLK SANDY LOAM, SUBSOIL.

No. 4 sand.—No potash feldspars. Practically pure quartz with rutile and apatite inclusions. Andesite present.

No. 5 sand.—Minerals other than quartz, 4.7 per cent. Quartz grains very clear and bright, mostly well rounded, with a few subangular and angular grains. Tourmaline, rutile, zircon, chlorite, magnetite, cyanite, hypersthene, weathered feldspars, and apatite inclusions in quartz are present.

Silt.—Minerals other than quartz, 60 per cent. Potash feldspars (orthoclase), 1 per cent, characterized by a large amount of highly kaolinized feldspars and the presence of sponge spicules. Epidote, chlorite, rutile, orthoclase, and zircons are also present.

(3) DECATUR CLAY LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 4 per cent. Potash feldspars, negligible. No muscovite. Magnetite, hematite, rutile inclosed in quartz, orthoclase, and epidote are present.

No. 5 sand.—Minerals other than quartz, 4.2 per cent. Potash feldspars (orthoclase), less than 0.5 per cent. No muscovite. The feldspars are much altered and few in number. Rutile, zircon, tourmaline, magnetite, and epidote are also present. Characterized by quartz crystals inclosing iron oxide.

Silt.—Minerals other than quartz, 39 per cent. Potash feldspars, 6 per cent. The feldspars are much altered. Epidote and chlorite are the predominating minerals. Tourmaline, rutile, and zircon are also present.

(4) DECATUR CLAY LOAM, SUBSOIL.

No. 4 sand.—No potash feldspars or muscovite found. The quartz is very impure. Magnetite, hematite, and rutile inclosed in quartz are present.

No. 5 sand.—Minerals other than quartz, 4 per cent. Potash feldspars less than 0.5 per cent. The quartz grains are well rounded and subangular. Tourmaline, zircon, rutile, magnetite, and calcite inclosed in quartz are also present. Characterized by quartz crystals.

Silt.—Minerals other than quartz, 37.5 per cent. Potash feldspars, 9 per cent. Zircon, epidote, tourmaline, magnetite, muscovite, chlorite, and sponge spicules are also present.

Gloucester stony loam, Nos. 11 and 12, shows a greater amount of silica in the subsoil and the iron and aluminum does not follow the general rule of being greater in amount in the subsoil. It would seem that the samples used in analysis might have been transposed, but the analysis of a second sample showed the same relation. This type is an exception to the rule, though the difference in the composition of the surface soil and the subsoil is not great.

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MINERALOGICAL COMPOSITION.

The micro-petrographical determinations were made by W. J. McCaughey, now of the University of Ohio, and William H. Fry, of this bureau. The examinations were made on separates made by mechanical analysis.

Quartz was universally present in all the soils examined and its presence is not noted in the individual reports.

(1) NORFOLK SANDY LOAM, SOIL.

No. 4 sand.—Practically pure quartz sand with apatite and rutile inclusions.

No. 5 sand.—Nearly pure quartz sand, with a few subangular, though mostly clear, well-rounded grains. Minerals other than quartz, 3.5 per cent. Rutile, zircon, ilmenite, and tourmaline present.

[1] Wis. Agr. Expt. Sta., Research Bul. No. 14. [2] Ky. Agr. Expt. Sta. Bul. No. 174.

Silt.—Minerals other than quartz, 40 per cent; potash feldspars, 7 per cent; muscovite, 0.5 per cent. Epidote is present in fairly large quantities. Hornblende, rutile, zircon, chlorite, magnetite, and sponge spicules are also present.

(2) NORFOLK SANDY LOAM, SUBSOIL.

No. 4 sand.—No potash feldspars. Practically pure quartz with rutile and apatite inclusions. Andesite present.

No. 5 sand.—Minerals other than quartz, 4.7 per cent. Quartz grains very clear and bright, mostly well rounded, with a few subangular and angular grains. Tourmaline, rutile, zircon, chlorite, magnetite, cyanite, hypersthene, weathered feldspars, and apatite inclusions in quartz are present.

Silt.—Minerals other than quartz, 60 per cent. Potash feldspars (orthoclase), 1 per cent, characterized by a large amount of highly kaolinized feldspars and the presence of sponge spicules. Epidote, chlorite, rutile, orthoclase, and zircons are also present.

(3) DECATUR CLAY LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 4 per cent. Potash feldspars, negligible. No muscovite. Magnetite, hematite, rutile inclosed in quartz, orthoclase, and epidote are present.

No. 5 sand.—Minerals other than quartz, 4.2 per cent. Potash feldspars (orthoclase), less than 0.5 per cent. No muscovite. The feldspars are much altered and few in number. Rutile, zircon, tourmaline, magnetite, and epidote are also present. Characterized by quartz crystals inclosing iron oxide.

Silt.—Minerals other than quartz, 39 per cent. Potash feldspars, 6 per cent. The feldspars are much altered. Epidote and chlorite are the predominating minerals. Tourmaline, rutile, and zircon are also present.

(4) DECATUR CLAY LOAM, SUBSOIL.

No. 4 sand.—No potash feldspars or muscovite found. The quartz is very impure. Magnetite, hematite, and rutile inclosed in quartz are present.

No. 5 sand.—Minerals other than quartz, 4 per cent. Potash feldspars less than 0.5 per cent. The quartz grains are well rounded and subangular. Tourmaline, zircon, rutile, magnetite, and calcite inclosed in quartz are also present. Characterized by quartz crystals.

Silt.—Minerals other than quartz, 37.5 per cent. Potash feldspars, 9 per cent. Zircon, epidote, tourmaline, magnetite, muscovite, chlorite, and sponge spicules are also present.

(12) GLOUCESTER STONY LOAM, SUBSOIL.

No. 4 sand.—Minerals other than quartz, 25 per cent. Potash feldspars (orthoclase and microcline), 6 per cent. Muscovite, 10 per cent. Biotite, phlogopite, oligoclase, garnet, labradorite, hornblende, and piedmontite are also present.

No. 5 sand.—Minerals other than quartz, 30 per cent. Potash feldspars (orthoclase), 5 per cent. Muscovite, 8 per cent. Phlogopite, hornblende, biotite, epidote, rutile, garnet, tourmaline, labradorite, andesite, andalusite, and enstatite are also present.

Silt.—Minerals other than quartz, 65 per cent. Potash feldspars (orthoclase), 2 per cent. Muscovite, 35 per cent. Phlogopite, biotite, garnet, hornblende, epidote, rutile, zircon, plagioclases, and augite are also present.

(13) CARRINGTON LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 6 per cent. Potash feldspars (orthoclase and microcline), 5 per cent. No muscovite. Magnetite and rutile inclosed in quartz are also present.

No. 5 sand.—Minerals other than quartz, 15 per cent. Potash feldspars (microcline and orthoclase), 10 per cent. No muscovite. Magnetite, hornblende, oligoclase, labradorite, albite, zircon, and corundum are also present.

Silt.—Minerals other than quartz, 30 per cent. Potash feldspars (orthoclase and muscovite), 12 per cent. Muscovite, 1 per cent. There are also present magnetite, hornblende, oligoclase, labradorite, rutile, epidote, and an isotropic mineral with an index of refraction below 1.50, making it impossible to accurately determine with available oils.

(14) FOX FINE SAND, SUBSOIL.

No. 4 sand.—Minerals other than quartz, 6 per cent. Potash feldspars (orthoclase), 4 per cent. No muscovite. Magnetite, apatite inclosed in quartz, labradorite, oligoclase, and hornblende are also present.

No. 5 sand.—Minerals other than quartz, 14 per cent. Potash feldspars (orthoclase and microcline), 8 per cent. No muscovite. Magnetite, labradorite, oligoclase, hornblende, rutile, and epidote are also present.

Silt.—Minerals other than quartz, 26 per cent. Potash feldspars (orthoclase and microcline), 10 per cent. Muscovite negligible. Magnetite, hornblende, epidote, plagioclases, rutile, biotite, and the same indetermined isotropic mineral as noted in No. 13 are also present.

(15) CECIL CLAY, SOIL.

No. 4 sand.—Minerals other than quartz, 4 per cent. Potash feldspars (orthoclase), 1.5 per cent. No muscovite. Magnetite, epidote, rutile inclosed in quartz, zircon, and augite are also present.

No. 5 sand.—Minerals other than quartz, 4.5 per cent. Potash feldspars (orthoclase), 1 per cent. Muscovite, 2 per cent. Epidote and augite are the predominant minerals. Chlorite, zircon, sillimanite, biotite, hypersthene, magnetite, augite, plagioclases, and hornblende are also present. The angular quartz grains are nearly transparent, but the subangular and rounded grains inclose iron oxide.

Silt.—Minerals other than quartz, 43 per cent. Potash feldspars (orthoclase), 2 per cent. Muscovite, 5 per cent. Chlorite very abundant. Biotite, sillimanite, zircon, epidote, hornblende, and feldspar residues are also present.

(16) CECIL CLAY, SOIL.

No. 4 sand.—Minerals other than quartz, 2 per cent. No potash feldspars. Muscovite, 1 per cent. Magnetite and biotite are also present.

No. 5 sand.—Minerals other than quartz, 4 per cent. Potash feldspars (orthoclase), 1 per cent. Muscovite, 1 per cent. Magnetite, biotite, hornblende, and feldspar residues are also present.

Silt.—Minerals other than quartz, 60 per cent. Potash feldspar (orthoclase), 3 per cent. Muscovite, 2 per cent. Feldspar residues and chlorite abundant. Epidote, zircon, magnetite, hematite, biotite, and plagioclases are present.

(17) CECIL SANDY LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 7 per cent. Potash feldspars (orthoclase), 1.5 per cent. No muscovite. Magnetite, rutile, inclosed in quartz, indeterminable plagioclase, and hornblende are also present.

No. 5 sand.—Minerals other than quartz, 8.3 per cent. Potash feldspars (microcline and orthoclase), 3.6 per cent. Microcline, orthoclase, and zircon are most abundant. Hornblende, muscovite, magnetite, chlorite, and apatite inclusions in quartz are present. Quartz grains are mostly clear, transparent, and angular to subangular.

Silt.—Minerals other than quartz, 30 per cent. Potash feldspars, 2 per cent. Muscovite, 2 per cent. Epidote, feldspar residues, zircon, chlorite, and magnetite are present.

(18) CECIL SANDY LOAM, SUBSOIL.

No. 5 sand.—Minerals other than quartz, 12 per cent. Potash feldspars (microcline and orthoclase), 3.6 per cent. Microcline, orthoclase, and zircon predominate. Hornblende, magnetite, chlorite, muscovite, biotite, epidote, plagioclase, and apatite inclusions in quartz are also present. The quartz consists of an equal number of clear transparent grains and those carrying inclusions or coatings of iron oxide.

Silt.—Minerals other than quartz, approximately 60 per cent. Potash feldspars not determinable. Muscovite, 4 per cent. Feldspar residues are abundant. Epidote, zircon, hornblende, chlorite, and magnetite are also present.

(19) DURHAM SANDY LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 25 per cent. Potash feldspars (orthoclase and microcline), 20 per cent. No muscovite. Magnetite, biotite, and zircon are also present.

No. 5 sand.—Minerals other than quartz, 30 per cent. Potash feldspars (microcline and orthoclase), 24 per cent. Muscovite, 1 per cent. Unaltered feldspars. Microcline and orthoclase predominate; zircon, rutile, magnetite, epidote, sillimanite, biotite, and quartz inclosing both zircon and apatite are also present. The quartz grains are beautifully clear and transparent and show no signs of chemical weathering.

Silt.—Minerals other than quartz, 55 per cent. Potash feldspars, 26 per cent. Muscovite, 2 per cent. Potash feldspars predominate; biotite, zircon, and epidote are fairly abundant. Tourmaline, magnetite, and chlorite are also present. The minerals do not show signs of alteration.

(20) DURHAM SANDY LOAM, SUBSOIL.

No. 5 sand.—Minerals other than quartz, 31 per cent. Potash feldspars (microcline and orthoclase), 25 per cent. Microcline, orthoclase, and epidote predominate; biotite, muscovite, chlorite, zircon, magnetite, and ilmenite are also present. There is little indication of chemical weathering.

Silt.—Minerals other than quartz, 60 per cent. Potash feldspars (orthoclase and microcline), 21 per cent. Muscovite, 2.5 per cent. Orthoclase, microcline, muscovite, and chlorite predominate; hornblende and rutile are also present.

(21) YORK SILT LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 4 per cent. No potash feldspars. Muscovite, 0.5 per cent. Magnetite, tourmaline, chlorite, and hornblende are also present.

No. 5 sand.—Minerals other than quartz, 6 per cent. No potash feldspars. Muscovite, 1 per cent. Chlorite, magnetite, epidote, and feldspar residues are also present.

Silt.—Minerals other than quartz, 80 per cent. No potash feldspars. Muscovite, 49 per cent. Characterized by the large amount of muscovite and feldspar residues. The latter are short and long needles having positive elongations and the refractive index and

birefringence of pyrophyllite. They are not to be confused with the fibrous variety of epidote which has a much higher refractive index and results from the alteration of plagioclase feldspars; chlorite and magnetite are also present.

(22) YORK SILT LOAM, SUBSOIL.

No. 4 sand.—Minerals other than quartz, 10 per cent. No potash feldspars. Muscovite, 2 per cent. Magnetite, biotite, and tourmaline present.

No. 5 sand.—Minerals other than quartz, 12.7 per cent. No potash feldspars. Muscovite, 1 per cent. Pyrophyllite present in large quantities. Magnetite, chlorite, tourmaline, and epidote also present.

Silt.—Minerals other than quartz, 85 per cent. Characterized by a high muscovite and pyrophyllite content. Rutile present.

(23) LOUISA LOAM, SOIL.

No. 5 sand.—Minerals other than quartz, 7.7 per cent. Magnetite, zircon, chlorite, muscovite, and apatite inclosed in quartz are present.

Silt.—Minerals other than quartz, 51 per cent. Potash feldspars, 3 per cent. Muscovite, 2.3 per cent. Magnetite, biotite, epidote, and chlorite predominate; tourmaline, zircon, and rutile are also present.

(24) LOUISA LOAM, SUBSOIL.

No. 5 sand.—Minerals other than quartz, 10 per cent. Magnetite, zircon, hematite, and apatite inclusions in quartz are present.

Silt.—Minerals other than quartz, 60 per cent. Potash feldspars (orthoclase), 2.5 per cent. Muscovite, 1.7 per cent. Biotite, chlorite, orthoclase, and muscovite predominate; epidote, zircon, magnetite, diallage, and rutile are also present.

(25) PENN SILT LOAM, SOIL.

No. 4 sand.—Minerals other than quartz, 10 per cent. Potash feldspars (orthoclase), 1 per cent. Muscovite, 6 per cent. Labradorite, zircon, apatite inclosed in quartz, hornblende, rutile, magnetite, and hematite are also present.

No. 5 sand.—Minerals other than quartz, 15 per cent. Potash feldspars (orthoclase), 6 per cent. Muscovite, 4 per cent. Magnetite, hematite, labradorite, tourmaline, hornblende, andalusite, zircon, and albite-oligoclase are also present.

Silt.—Minerals other than quartz, 18 per cent. Potash feldspars (orthoclase), 5 per cent. Muscovite, 9 per cent. Tourmaline, biotite, epidote, hornblende, albite, apatite, and augite are also present.

(26) PENN SILT LOAM, SUBSOIL.

No. 4 sand.—Minerals other than quartz, 14 per cent. Potash feldspars (orthoclase), 5 per cent. Muscovite, 7 per cent. Magnetite-biotite, rutile inclosed in quartz, apatite inclosed in quartz, and albite-oligoclase are also present.

No. 5 sand.—Minerals other than quartz, 15 per cent. Potash feldspars (orthoclase), 4 per cent. Muscovite, 6 per cent. Magnetite, biotite, tourmaline, oligoclase, zircon, epidote, hypersthene, labradorite, and hornblende are also present.

Silt.—Minerals other than quartz, 40 per cent. Potash feldspars (orthoclase), 4 per cent. Muscovite, 15 per cent. Tourmaline, biotite, epidote, hornblende, albite, and augite are also present.

DISCUSSION OF THE MINERALOGICAL DATA.

The general results of the mineralogical examinations support the conclusions already given by McCaughey and Fry.[1] The soils of the Limestone Valley and Upland province are unique in containing quartz crystals with inclusions of calcite and iron oxide. In general soils of the glaciated areas are higher in minerals other than quartz than soils of the other areas.

Apatite is reported in 11 out of the 26 samples. The average of the phosphoric-acid content of the soils is 0.11 P_2O_5, whereas the average of those in which apatite was not recognized is 0.15 per cent. This indicates either that the phosphoric acid (P_2O_5) of soils occurs in other minerals either as a characteristic part or accidentally, or that a large part of the apatite is in the clay group, and thus escapes detection.

Types in which the titanium was larger or of about the same amount in the surface as compared to the subsoil contained rutile or rutile inclusions in quartz. The percentage of minerals other than quartz is higher in the finer separates, and particularly is this true in soils of the Piedmont Plateau province. The amount of minerals other than quartz is greater in the subsoil than in the surface soil, for the respective separates.

Tourmaline is present in the particles coarser than clay in 18 samples. This mineral is particularly interesting for it carries boron as an essential constituent. In some cases tourmaline occurs in relatively large amounts, indicating the presence of boron in more than mere traces. The micas, generally muscovite, occur in 24 samples. Phlogopite, of which fluorine is an essential constituent, occurs in soils Nos. 10, 11, and 12. Fluorine occurs in all micas in amounts varying from traces to several per cent, and therefore we would expect these soils to contain fluorine

The amounts of potash feldspars and micas in various soils have been determined by McCaughey and Fry, and is given in Tables III and IV.

[1] Bull. 91, Bureau of Soils, U. S. Dept. Agriculture (1913).

TABLE III.—*Percentage of potash feldspars and muscovite and the percentage of separates in the soil.*

No.	Feldspar.			Muscovite.			Mechanical analysis [1] separate in the soil.		
	In No. 4 sands.	In No. 5 sands.	In silt.	In No. 4 sands.	In No. 5 sands.	In silt.	No. 4 sand.	No. 5 sand.	Silt.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	N. F.	N. F.	7.0	N. D.	N. D.	0.5	23.9	17.3	18.5
2	N. F.	0.5	1.0	N. D.	N. D.	.5	19.5	14.1	15.2
3	N. D.	.5	6.0	N. F.	N. F.	N. F.	10.4	9.6	47.9
4	N. D.	.5	9.0	N. D.	P.	P.	6.2	6.9	45.2
5	N. D.	8.0	11.0	N. D.	N. D.	2.0	4.8	7.6	63.9
6	N. D.	11.5	18.0	N. D.	N. D.	2.0	7.4	8.6	52.9
7	4.0	4.4	8.0	N. D.	N. D.	P.	4.3	13.0	58.1
8	4.0	5.7	5.0	N. D.	N. D.	1.0	6.3	11.5	52.6
9	2.0	10.0	12.0	1.0	2.0	4.0	.4	6.0	72.6
10	3.0	5.0	8.0	2.0	5.0	7.0	1.3	4.4	68.2
11	2.0	4.0	2.0	5.0	7.0	30.0	21.9	15.0	20.9
12	6.0	5.0	2.0	10.0	*8.0	35.0	31.9	18.7	17.9
13	5.0	10.0	12.0	N. F.	N. F.	1.0	23.6	11.3	32.3
14	4.0	8.0	10.0	N. F.	N. F.	1.0	27.5	12.3	28.4
15	1.5	1.0	2.0	N. F.	2.0	5.0	7.4	6.8	38.1
16	N. F.	1.0	3.0	1.0	1.0	2.0	1.0	3.0	47.6
17	1.5	3.6	2.0	N. D.	N. D.	2.0	13.8	11.6	26.2
18	N. D.	3.6	N. D.	N. D.	N. D.	4.0	4.2	5.0	27.6
19	20.0	24.0	26.0	N. D.	1.0	2.0	24.1	14.4	20.3
20	*20	25.0	21.0	N. D.	N. D.	2.5	17.7	9.6	18.0
21	N. F.	N. F.	N. F.	0.5	1.0	49.0	1.9	29.4	60.9
22	N. F.	N. F.	N. F.	2.0	1.0	54.0	2.5	28.9	63.5
23	N. D.	N. F.	3.0	N. D.	N. F.	2.3	17.1	20.4	39.1
24	N. D.	N. F.	2.5	N. D.	N. F.	1.7	12.6	16.7	32.2
25	1.0	6.0	5.0	6.0	4.0	9.0	3.7	16.1	60.2
26	5.0	4.0	4.0	7.0	6.0	15.0	3.1	14.5	59.0

[1] Mechanical analysis by L. A. Kolbe.

N. F. Not found. N. D. Not determined. P. Present. *Extrapolated.

TABLE IV.—*Showing the amount of potash feldspars and muscovite in some types of American soil.*

Number of sample.	Depth.	Feldspars.				Muscovite.				Quantity per acre to the depth indicated.		Quantity per acre to a depth of 3 feet.	
		Per cent in No. 4 sand.	Per cent in No. 5 sand.	Per cent in silt.	Per cent, total.	Per cent in No. 4 sand.	Per cent in No. 5 sand.	Per cent in silt.	Per cent, total.	Feldspars.	Muscovite.	Feldspars.	Mica.
	Inches.									*Tons.*	*Tons.*	*Tons.*	*Tons.*
1	0–14	N. F.	N. F.	1.30	1.3	N. D.	N. D.	0.09	0.1	30	2	.....	.....
2	14–36	N. F.	0.07	.15	.2	N. D.	N. D.	.08	.1	7	4	37	6
3	0– 4	N. D.	.05	2.87	2.9	N. F.	N. F.	N. F.	N. F.	19	N. F.	.....	.....
4	4–36	N. D.	.03	4.07	4.1	N. D.	P.	P.	P.	218	Neg.	237	Neg.
5	0– 8	N. D.	.61	7.07	7.6	N. D.	N. D.	1.28	1.3	102	17	.....	.....
6	8–36	N. D.	.99	9.52	10.5	N. D.	N. D.	1.06	1.1	489	51	591	68
7	0– 8	.17	.57	5.17	5.9	N. D.	N. D.	P.	P.	78	Neg.	.....	.....
8	8–36	.25	.66	2.63	3.5	N. D.	N. D.	.39	.4	163	19	241	19
9	0–15	.01	.60	2.90	3.5	Neg.	.12	2.90	3.0	88	75	.....	.....
10	15–36	.04	.20	5.46	5.7	.03	.22	4.77	5.0	200	175	288	250
11	0– 8	.44	.60	.42	1.5	1.10	1.05	6.27	8.4	20	112	.....	.....
12	8–36	1.91	.94	.36	3.2	3.19	1.50	6.26	11.0	149	513	169	625
13	0–11	1.18	1.13	3.88	6.2	N. F.	N. F.	.32	.3	114	6	.....	.....
14	11–36	1.10	.98	2.84	4.9	N. F.	N. F.	.28	.3	206	12	320	18
15	0– 6	.11	.07	.76	.9	N. F.	.14	1.91	2.1	9	21	.....	.....
16	6–36	N. F.	.003	1.43	1.4	Neg.	Neg.	.95	1.0	70	50	79	71
17	0– 8	.21	.42	.52	1.2	N. D.	N. D.	.52	.5	16	7	.....	.....
18	8–36	N. D.	.18	N. D.	.2	N. D.	N. D.	1.10	1.1	9	51	25	58
19	0–10	4.82	3.46	5.28	13.6	N. D.	.14	.41	.6	227	10	.....	.....
20	10–36	*3.54	2.40	2.78	9.7	N. D.	N. D.	.45	.5	431	22	648	32
21	0–10	N. F.	N. F.	N. F.	N. F.	.01	.29	29.8	30.1	N. F.	501	.....	.....
22	10–36	N. F.	N. F.	N. F.	N. F.	.05	.29	34.3	34.6	N. F.	1,500	N. F.	2,000
23	0–12	N. D.	N. F.	1.17	1.2	N. D.	N. F.	.90	.9	24	18	.....	.....
24	12–36	N. D.	N. F.	.80	.8	N. D.	N. F.	.55	.6	32	24	56	42
25	0– 9	.04	.97	3.01	4.0	.22	.64	5.42	6.3	60	95	.....	.....
26	9–36	.16	.58	2.36	3.1	.22	.87	8.85	9.9	140	446	200	541

N. F.—Not found. N. D.—Not determined. P.—Present. Neg.—Negligible. * Extrapolated.

The method applied by them is as follows: Ten grams of the sample were separated into sands of five different grades and into silts and clays. The determinations were made on subsamples of very fine sand (1–0.05 mm. diameter) and on the coarser silts (0.05–0.005 mm. diameter). Six or eight counts were made on each sample, and from the number of potash feldspars and micas and the total number of particles present the percentages of the forenamed minerals have been determined.[1]

From this data and from the amount of each separate in the soil the minimum percentages of potash feldspars and muscovite have been determined. The minerals in question in the coarser sands and clays are not included, for these separates are difficult to examine. The percentage of potash-bearing minerals in the clay is very often higher than in any other separate, as shown by Failyer, Smith, and Wade.[2]

Table V shows the relation between the total amount of potash in the soil as shown by fusion analysis and that estimated from the amount of potash minerals determined in the sands and coarse silts. The theoretical[3] percentage of potash in orthoclase was taken as the basis for calculation and 8 per cent was used for muscovite.

TABLE V.—*Relation between the actual amount of potash present and the amount of potash in the minerals estimated.*

Number of soil sample.	Potash.	
	Actual.	From mineralogical data.
	Per cent.	*Per cent.*
1	0.10	0.22
16	.61	.32
19	3.96	2.33
22	4.07	2.77

Excepting sample No. 1, where the actual amount is small—and for this reason the exception is not important—there is much more potash present than is accounted for mineralogically. These figures simply show that the estimates based on an examination of the minerals are certainly not too high.

In all the soil types examined there were present either potash feldspars or potash mica in large amounts. In one case only is potash feldspar lacking and, likewise, muscovite was not found in one

[1] In this calculation it is assumed that in each mechanical subdivision the average weight of the particles of each mineral in question is equal to the average weight of the particles of any other mineral. While this is not strictly true, it is sufficiently accurate for the purpose. The error is probably greatest in the mica determinations.

[2] Bul. 54, Bureau of Soils, U. S. Dept. Agriculture.

[3] Orthoclase as ordinarily found does not contain the calculated amount of potash.

case. But in both these cases the other potash mineral, i. e., feldspar or mica, was present, and in large amounts. Therefore the potash in any of these soils was not only that held by physical or indefinite chemical absorption, but that contained in original minerals which will slowly yield their potash to the soil solution by decomposition extending through a long period of time.

It is interesting to note that zeolites and rare earth minerals were not recognized.

CONCLUSIONS.

(1) The rarer elements, chromium, vanadium, rare earths, zirconium, barium, strontium, lithium, and rubidium, were present in all soils examined. Chromium ranged from a trace to 0.025 per cent; vanadium, from 0.01 per cent to 0.08 per cent; rare earths, from 0.01 per cent to 0.08 per cent; zirconium, from 0.003 per cent to 0.08 per cent; barium, from 0.004 per cent to 0.360 per cent; strontium, from 0.01 per cent to 0.11 per cent. Lithium was found in spectroscopic traces only. Boron is indicated in 18 soils by the presence of tourmaline and fluorine in 24 soils by the presence of micas.

(2) Molybdenum was found in only two samples, the surface soils of the Durham sandy loam and the York silt loam.

(3) Cæsium was found in only one soil.

(4) While it seems likely that copper, nickel, and cobalt are present in soils, neither the amounts nor even the presence of these elements has been established with certainty.

(5) Silica is higher in the surface soil than in the subsoil, and aluminum, iron, and, generally, titanium, are higher in the subsoil. Potash and magnesium are higher in the subsoil. Manganese and phosphorous concentrate in the surface soil.

(6) The sulphur content is low, ranging from 0.03 per cent SO_3 to 0.39 per cent SO_3 with an average of 0.13 per cent.

(7) The evidence that soils contain the more important rock-forming minerals is strengthened by the mineralogical examinations described.

(8) There is an abundance of potash minerals in the soil. Samples Nos. 2 and 3, Decatur clay loam, do not contain potash mica in determinable amounts, though there are large quantities of potash feldspars present. Samples Nos. 21 and 22, York silt loam, do not contain determinable amounts of potash feldspars, but to offset this there are large quantities of potash mica. Taken to a depth of 3 feet the potash mineral content of the soil varied from 43 to 2,000 tons to the acre.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1914

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